SHIPBORNE AND GROUND-BASED OBSERVATIONS OF CLOUDS IN THE SUBANTARCTIC AND THE SOUTHERN OCEAN

Peter Kuma[1], Adrian McDonald[1], Simon Parsons[1], Sean Hartery[1,2], Mike Harvey[2]

[1]Department of Physics and Astronomy, University of Canterbury, Christchurch, New Zealand; [2]NIWA, Wellington, New Zealand

Clouds in the Southern Ocean are poorly represented in current general circulation models, resulting in a substantial shortwave radiation bias. Our current understanding of cloud in this region is hindered by scarce observations, with satellite cloud observations providing limited views of low clouds. As part of the Deep South National Science Challenge we are creating a dataset of shipborne and ground-based cloud observations spanning a significant part of the Southern Ocean over multiple years. We will use this dataset to support the development of the nascent New Zealand Earth System Model (NZESM) by comparing observations with results from equivalent model instrument simulators using the Cloud Feedback Model Intercomparison Project (CFMIP) Observation Simulator Package (COSP), and also share this dataset with others interested in cloud climatology in the Southern Ocean.

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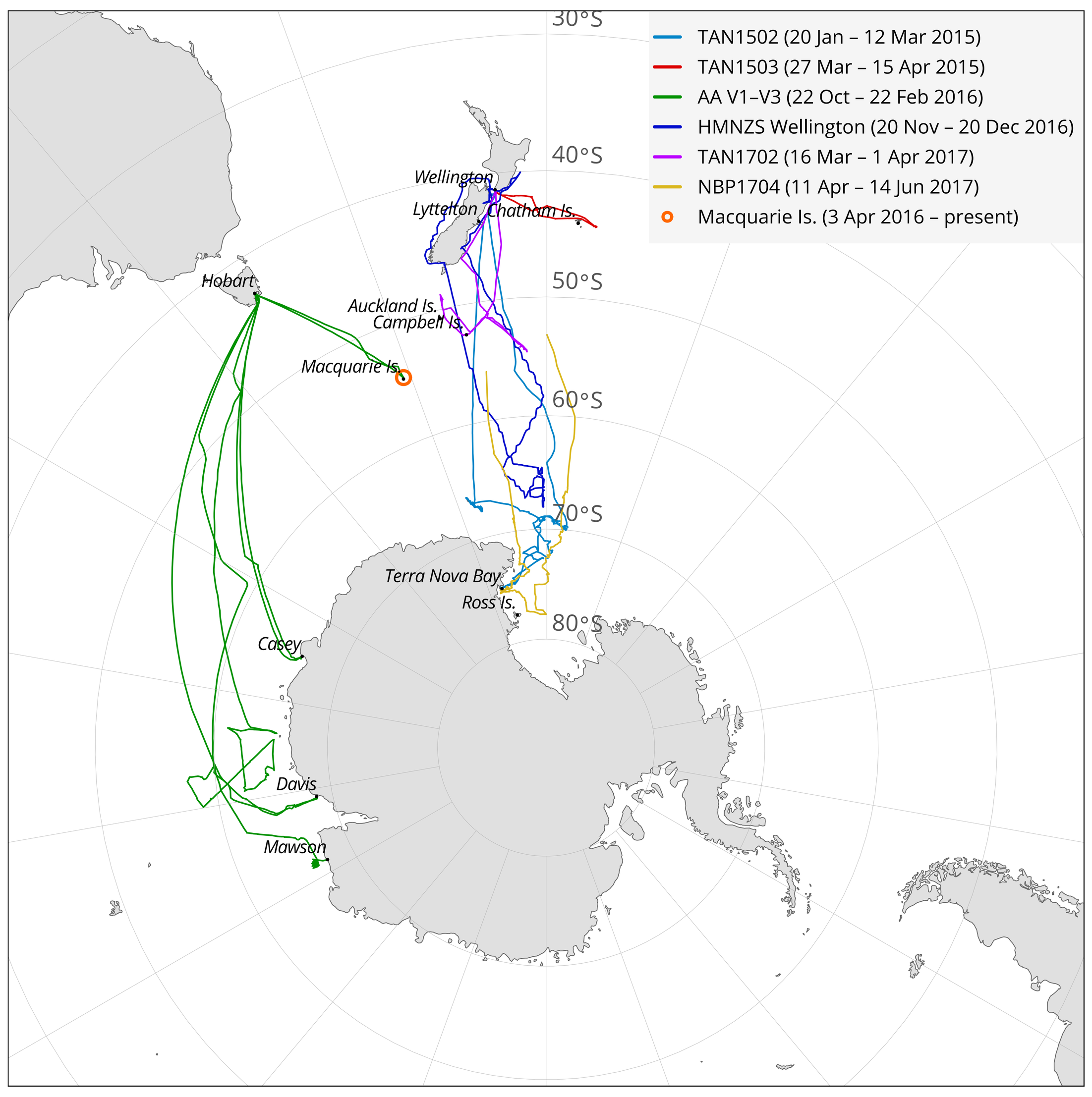
Observational Campaigns



We have deployed our instruments on 6 voyages of RV Tangaroa, Aurora Australis, HMNZS Wellington and RV Nathaniel B. Palmer and on Macquarie Island between January 2015 and June 2017. The instruments involved ceilometers, micro rain radar, and an auxiliary sky-observing camera. Atmospheric soundings and aerosol measurements were also performed on some voyages.

In total, we have collected 269 days of shipborne observations and 445 days of ground-based observations over 3 years, covering October–June by shipborne observations and year-round by ground observations on Macquarie Island.

Figure 1 | Map showing ship tracks of the observation campaigns and the location of ground-based measurements on Macquarie Island. Ships: RV Tangaroa (TAN), Aurora Australis (AA), HMNZS Wellington, RV Nathaniel B. Palmer (NBP).

Instruments

Simultaneous measurements from multiple instruments allow for a comprehensive assessment of clouds and aerosols which would not be possible with any single instrument. Ground-based measurements are valuable in complementing satellite cloud observations from CloudSat, CALIPSO, ISCCP and MODIS. This is especially true for boundary layer clouds, which is the predominant cloud type in the Southern Ocean, and which spaceborne instruments may not be able to observe due to overlying clouds or ground clutter.

Ceilometer

Lufft CHM 15k

Lufft CHM 15k is a 1064 nm near-infrared ceilometer with a vertical range of 15 km. It is especially suited for measuring cloud base height and cloud fraction, but cloud layers and boundary layer height can also be derived.

Figure A1 | Lufft CHM 15k on RV Nathaniel B. Palmer in Lyttelton, en route to Terra Nova Bay (2017).

Micro rain radar

Metek MRR-2

Metek MRR-2 is a vertically-pointing 24 GHz K-band frequency-modulated continuous-wave (FMCW) radar, capable of observing precipitation and to a lesser extent cloud droplets.

It was deployed on the HMNZS Wellington (2016) and TAN1702 voyages.

Figure A4 | Metek MRR-2 on RV Tangaroa in Wellington, en route to Campbell Plateau (2017).

Sky-viewing Camera

A vertically-pointing camera was available on the TAN1702 and AA V1–V3 voyages, capturing images near continuously.

Ceilometer

Vaisala CL51

Vaisala CL51 is a 910 nm ceilometer with a measurement range of 15 km.

Similar to Lufft CHM 15k, it is suitable for identifying cloud base height, cloud fraction, cloud layers and boundary layer height.

Figure A2 | Installation of Vaisala CL51 on Macquarie Island (2016).

Radiosondes

100+ atmospheric soundings of temperature, relative humidity, pressure, wind speed and wind direction are available between the TAN1702 and NBP1704 voyages.

Aerosol Measurements

Aerosol instruments were operated on the TAN1702 voyage: Passive Cavity Aerosol Spectrometer Probe (PCASP-100X; Droplet Measurement Technologies), counting aerosol at 0.1–3 µm; Condensation Particle Counter (CPC 3010; TSI Inc.), counting aerosol > 10 nm; static diffusion CCN counter (Model M1 CCN; DH Associates), counting aerosol which grew via condensation at 0.5% supersaturation; Lightweight Optical Aerosol Counter (LOAC; Meteomodem), recording aerosol size spectra at 0.2–50 µm; optical particle counters, measuring concentration of particles at 1–10 µm, PM10 and PM2.5.

Figure A3 | Optical particle counters on TAN1702 (2017).

Preliminary Results

Here we present selected preliminary observations. Figure 2 shows sample profiles from the ceilometer and a radiosonde on the TAN1702 RV Tangaroa voyage. The profile with a predominant stratocumulus clouds is representative of conditions observed throughout the voyage.

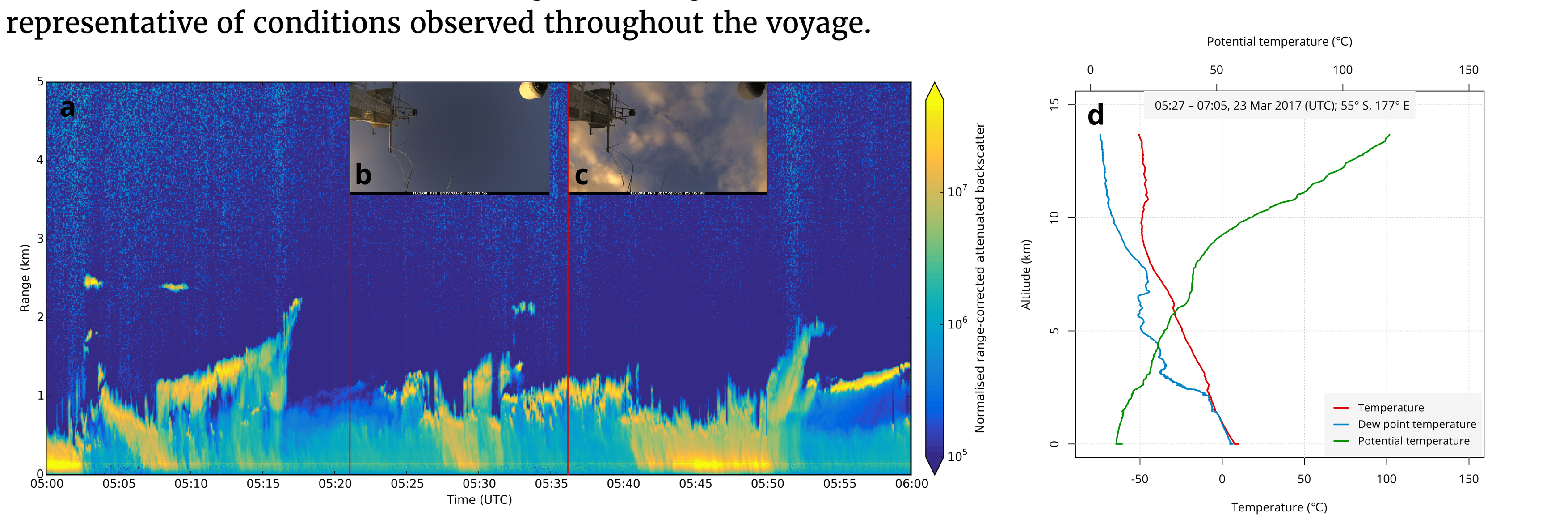


Figure 2 | Samples from a number of instruments observed at about the same time on the TAN1702 voyage. a, ceilometer (Lufft CHM 15k) attenuated backscatter, **b, c,** sky camera views, **d,** atmospheric sounding profile. Time of the camera pictures is indicated by red vertical lines. Note that even though 5:21 UTC is a clear sky profile, there is a significant backscatter from the boundary layer.

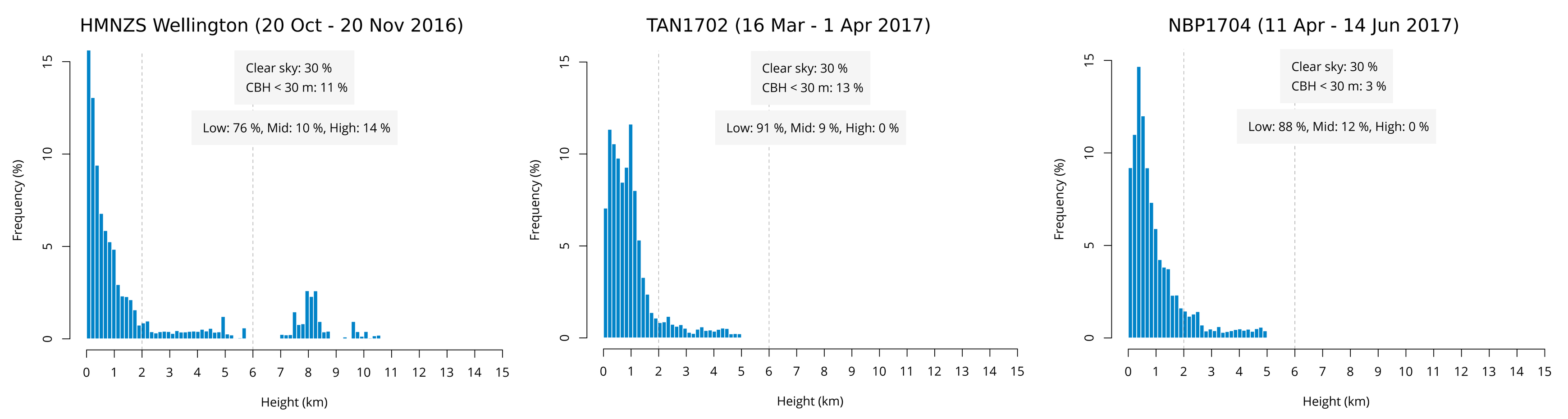


Figure 3 | Cloud base height distribution from 3 voyages measured by the Lufft CHM 15k ceilometer. 'CBH < 30 m' is the fraction of profiles where cloud base height was less than 30 m. 'Low', 'Mid' and 'High' are fractions of low, middle and high cloud bases, respectively (boundaries between low, middle and high cloud base are defined at 2 and 6 km above sea level, respectively). 'Clear sky' is the fraction of clear sky profiles.

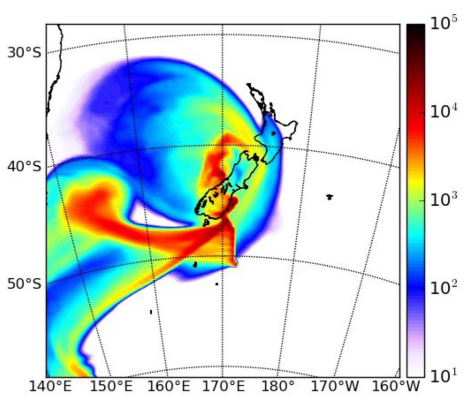


Figure 4 | Particle trajectory simulation for the TAN1702 voyage. Particle simulations were launched every 10 min using the ship location to track the air mass history of the observations. Displayed is the sum of all integrated 5-day footprints, which estimates the length of time an air parcel spent near the sea surface.

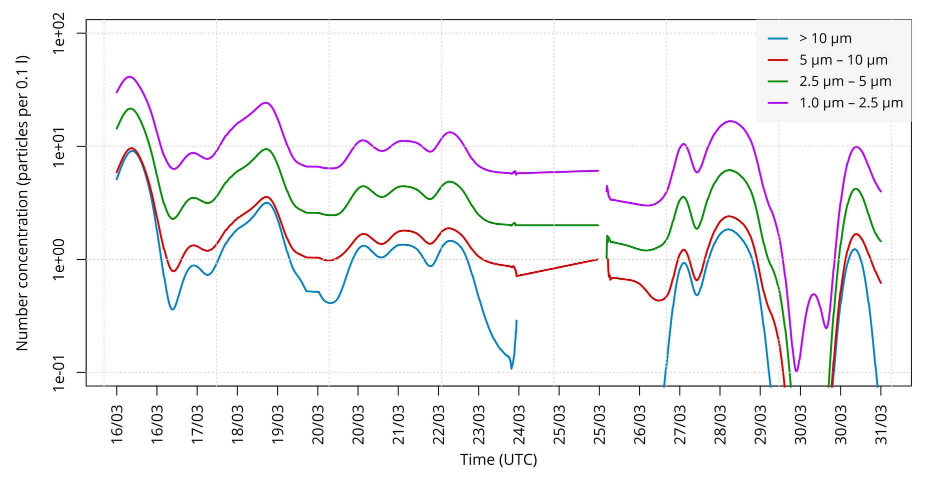


Figure 5 | Particle concentration from an optical particle counter on the TAN1702 voyage. Shown are concentrations of particles in a number of size ranges over the 16-day period of the voyage. The time series were smoothed with a Gaussian kernel with an interquartile width of 12 h.

Figure 3 shows the cloud base height distribution from three voyages. It is notable that we observed predominantly low clouds (although mid- and high-level clouds might have been obscured), and these accounted for 76–91% of observed clouds. Clear sky profiles were observed 30% of time in all cases. Notable is also the similarity of the distributions observed during different time periods of the voyages and covering different parts of the Southern Ocean.

Figure 4 shows the result of a particle trajectory simulation using FLEXPART-WRF along the TAN1702 voyage track. This allows us to identify locations of aerosol sources affecting the in situ observations.

Figure 5 shows preliminary results from an optical particle counter on TAN1702. The instrument will however require comparison to a reference instrument before the quality of the data can be established. Correlating the presence of aerosols with cloud measurements will allow us to explore the role of oceanic aerosols in cloud formation.

Planned Work and Future Deployments

Planned work will largely consist of comparison of the observational dataset with NZESM simulations. Because only few cloud characteristics such as cloud base height and cloud fraction can be compared directly without considering the limited view of the instruments, the comparison will involve development of a ceilometer simulator within the CFMIP Observation Simulator Package (COSP), and a cloud detection algorithm applicable to both observed and simulated profiles. We also hope to extend applicability of the dataset by correlating with spaceborne cloud observations.

Planned future deployments include a 2018 and 2019 Antarctic voyages of RV Tangaroa, future voyages of the Royal New Zealand Navy vessels and a ceilometer deployment on Davis station. We are also actively looking for other possibilities to deploy on 'ships of opportunity'.

Acknowledgements

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If you are interested in using the dataset or have any questions please contact Peter Kuma: **peter.kuma@pg.canterbury.ac.nz**